In-air calibration of new high dose rate ^{60}Co brachytherapy sources: results of measurements on a GZP6 brachytherapy afterloading unit

Asghar MESBAHI[1,2*], Alireza NASERI

Received: 9.07.07
Accepted: 26.09.07
Subject: original paper

[1]Medical Physics Department, Medical School, Tabriz University of Medical Sciences, Tabriz, Iran.
[2]Radiation Oncology Department, Imam-Khomeini Hospital, Tabriz, Iran

***Address for correspondence**:
Asghar Mesbahi
asgharmesbahi@yahoo.com
Phone and Fax:
0098-0411-3364660.

SUMMARY

BACKGROUND: The air kerma rate of brachytherapy sources should be determined accurately by the manufacturer and medical physicists before clinical use.

AIM: In the current study the air kerma rate of three new ^{60}Co high dose rate (HDR) brachytherapy sources was obtained by in-air measurements and a Farmer type ionization chamber.

MATERIALS/METHODS: Three ^{60}Co sources of a brachytherapy afterloading unit, GZP6, were calibrated in free air using a Farmer type chamber which was calibrated in terms of air kerma in an external teletherapy ^{60}Co beam. Several correction factors including scatter correction and non-uniformity correction factors were derived and used for in-air calibrations.

RESULTS: The measured air kerma rates for all sources were in good agreement (less than 2.5%) with manufacturer-provided data, and the reliability of the air kerma rates of sources was validated for clinical application.

CONCLUSION: In-air calibration of ^{60}Co HDR sources can be performed using a Farmer type ionization chamber with acceptable accuracy. However, accurate distance measurement and reproducible measurement setup are required.

BACKGROUND

The advanced production of artificial isotopes in recent decades and the introduction of remote afterloading techniques allowed the use of radionuclides of high-dose-rate radioactivity (HDR) in brachytherapy. ^{192}Ir and ^{60}Co sources are used frequently for HDR brachytherapy treatments due to their high specific activity [1, 2]. Calibration of brachytherapy sources are performed at the manufacturer's site using a well type chamber or by in-air measurement using a thimble chamber. On the other hand, vendors usually assign large uncertainties to their stated calibration values, in some cases up to ±10%. End-user calibration of brachytherapy sources is necessary, not only to check vendor stated calibration but to ensure traceability to internationally accepted standards [3]. It is also recommended by the American Association of Physicists in Medicine (AAPM) that "Each institution planning to provide brachytherapy should have the ability to independently verify the source strength provided by the manufacturer" [4].

The reference air kerma rate is the recommended quantity for specifying brachytherapy sources [3, 4]. It is defined by the International Commission on Radiation Units and Measurements (ICRU) as the kerma rate to air, in free space, at a reference distance of one metre, corrected for air attenuation and scattering [4]. For needles, tubes and other similar rigid sources, the direction from the source centre to the reference point should be at right angles to the long axis of the source.

In-air calibration using a Farmer type chamber is influenced by several factors which may increase the uncertainty of measurements. Several works have reported the role of these factors and approaches to minimize their effects on measurement accuracy [2, 5–8]. The effect of scattered radiation on in-air calibration was studied and they concluded that amount of scattered radiation changes with respect to the surrounding concrete scattering surfaces but it becomes constant at a distance greater than 100 cm from the wall of the room. [7, 9].

AIM

In this study the reference air kerma rates of three ^{60}Co HDR sources were measured in air using a Farmer type chamber before clinical use. The results of measurement were compared with the manufacturer-provided air kerma rates of these sources.

MATERIALS AND METHODS

HDR ^{60}Co sources

In-air strength calibration was performed for three HDR ^{60}Co sources of a GZP6 afterloading unit (Nuclear Power Institute of China). This unit uses six linear braid type sources including one stepping and five non-stepping sources for intracavitary treatment such as cervix, rectum, oesophagus and nasopharynx malignancies. The sources consist of ^{60}Co active cylinders (length=3.5 cm, diameter=1.5 mm) sealed by titanium capsules and inactive steel balls (diameter=1.5 mm) which are covered by a steel spring. The position of active elements is constant in the source braid and is not changed for different treatments. Each braid source is situated in a given channel and is loaded independently by a mechanical transport system from a shielded container to applicators for treatment. However, channels 3 and 4 are loaded simultaneously and used for ovoid applicators. A schematic representation of the three sources used in this study is shown in Fig.1.

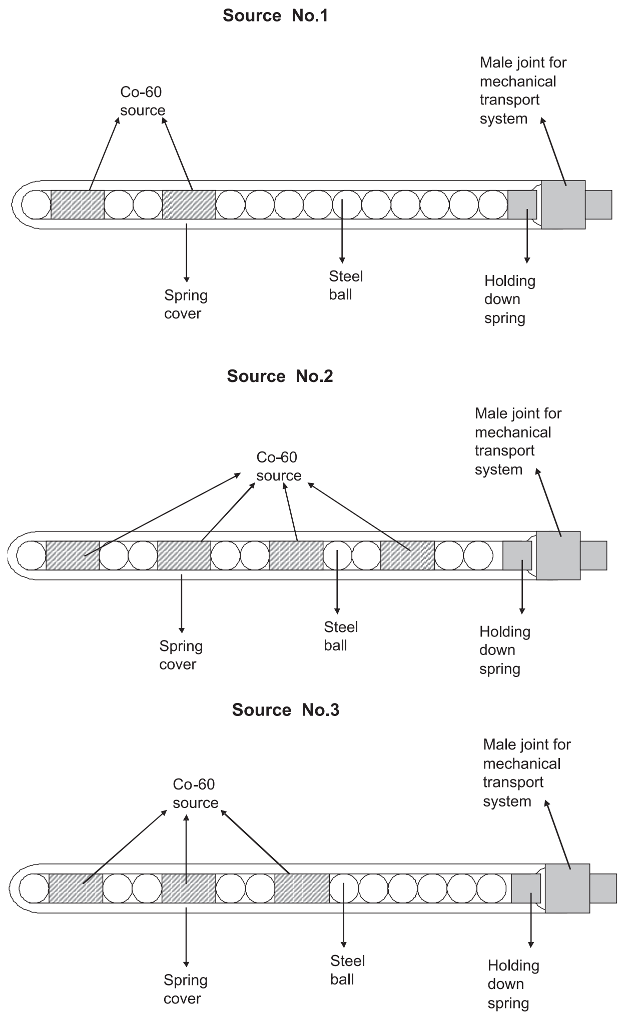

Fig. 1. Schematic diagrams of GZP6 ^{60}Co braid type sources used for intracavitary treatments.

Measurement setup

A Farmer type ionization chamber (FC65-P) with volume of 0.65 cm^3 (Scanditronix/Wellhofer) and a build-up cap (PMMA) with thickness of 0.5 g/cm^2 was used for in-air measurements. The chamber was calibrated in terms of air kerma at the actual photon energy of the brachytherapy source, and the calibration was done in an external photon beam of a ^{60}Co teletherapy unit at the Iranian Atomic Energy Organization.

The applicator was placed on the treatment couch and fixed using its fixation systems. The chamber was placed on the same couch and was fixed using an acrylic holder at various distances from the applicators. The measurement setup is shown in Fig. 2. For each measurement position the vertical position and also the distance from the source applicator was measured using a scale attached to the couch and also by a ruler. This was done independently by two dosimetrists. We assumed a geometric uncertainty of ±2 mm for our measurements. To have reliable measurements the distance between the chamber centre and the centre of the source must be at least 10 times the length of the source in order to ensure that the error introduced due to the point

Fig. 2. Measurement setup shows the applicator and Farmer type 0.65 cm³ ionization chamber.

source approximation is less than 0.1% [3]. The active length of sources were 10, 23 and 16.5 mm for sources 1, 2 and 3 respectively. So the distance of 20 cm was used for air kerma measurements. Additionally, the measurements were performed at two other distances of 30 and 40 cm between source and ionization chamber to obtain the scatter correction factor. The scatter correction factor and its method of measurement will be explained in the next section.

Calculation formalism and methods

The reference air kerma rate of ^{60}Co HDR sources is not directly measured at the distance of one metre due to low signals and the possible high leakage currents of the ionization chambers. It is usually measured at the short distances of 10 to 40 cm [3]. According to the IAEA [3] report, the reference air kerma rate, KR, can be determined from measurements made free in air using the equation:

$$K_R = N_K \cdot (M_u/t) \cdot k_{air} \cdot k_{scatt} \cdot k_n \, (d/d_{ref})^2 \quad [3]$$

where N_K is the air kerma calibration factor of the ionization chamber at the actual photon energy; M_u is the measured charge collected during the time t and corrected for ambient temperature and pressure, recombination losses and source transit time for afterloading systems; k_{air} is the correction for attenuation of the primary photons by the air between the source and the chamber; k_{scatt} is the correction for scattered radiation from the walls, floor, measurement setup, air; k_n is the non-uniformity correction factor, accounting for the non-uniform electron fluence within the air cavity; d is the measurement distance, i.e. the distance between the centre of the source and the centre of the ionization chamber, and d_{ref} is the reference distance of 1 m.

Scatter correction factor for our measurement setup

The measurement table and setup was placed in the centre of the treatment room and at a minimum distance of 1.5 m from the nearest wall and floor to minimize the contribution of scattered radiation. The multiple distance method was used to obtain the scatter correction factor for the measurement [7, 10]. In this method, the measurements are made in a series of distances. The rationale of this method is that the measured air kerma at a distance is the sum of the primary and scatter radiation. The primary radiation follows the inverse square law, but the scatter radiation remains constant for all distances. Our approach to derive the scatter correction factor was precisely based on the recommendation of IAEA report No.1274.

In order to derive the correction c that yields the "true" centre-to-centre source to chamber distances, d', let us express the distance between the chamber and the source by the formula:

$$d' = d + c$$

where d' is the centre-to-centre source chamber distance accounting for the offset c in the distance, d is the apparent centre-to-centre source chamber distance and c is the offset in the setup distance.

The contribution of scatter radiation to the air kerma rate, K_s, is included in the measured air kerma rate, K(d'). Thus, the air kerma value due to the primary photons only, $K_P(d')$, is given by $K_P(d') = K(d') - K_S$.

Using the two above equations we will have the practical equation to obtain three quantities including $K_P(d')$, K_s and c.

$$K_P(d') = (K(d') - K_s)\,(d+c)^2/(d')^2$$

We should keep in mind that to solve this equation we need measurements at least at three distances. For all sources, measurements at distances of 20, 30 and 40 cm were used to yield those three unknown quantities. Finally, the scatter correction factor k_{scatt} was determined using the following formula:

$$k_{scatt}=1-K_s/K(d')$$

The non-uniformity correction factor

In the in-air measurements of dose rate for brachytherapy sources, considerable variation of the photon fluence over the different parts of the chamber exists due to the non-collimated geometry and high divergence of the incident photons. The non-uniformity correction factor, k_n, is applied to convert the measured charge or current into air kerma rate at the measurement distance. This factor depends on several factors including the shape and dimensions of the ionization chamber, measurement distance and the source geometry, material in the inner wall of the chamber, and energy of the photons emitted from the source. To derive k_n the following equations were used:

$$k_n=1/A_{pn}(d) \text{ and } A_{pn}(d)=A^{KR}_{pn}(d)+\omega A'_{pn}(d)$$

where $1/A^{KR}_{pn}(d)$ is the non-uniformity correction factor obtained from the isotropic theory of Kondo and Randolph [11] and $1/A_{pn}(d)$ is the non-uniformity correction factor according to the anisotropic theory of Bielajew [12]. $A'_{pn}(d)$ takes into account the anisotropic electron fluence within the air cavity and the degree of anisotropy is given by the energy and material dependent factor ω. The ω factor for the chamber used in the measurements was derived as 0.992 according to the values provided by the IAEA report (TableVI) [3]. To calculate the non-uniformity correction factor, the values listed for $A^{KR}_{pn}(d)$ and $A'_{pn}(d)$ in Tables VII and VIII were used [3].

Other corrections

For k_{air} which corrects for the attenuation of primary radiation at a given distance, according to report No.1274, there was no need for correction for ^{60}Co sources at distances from 10 to 100 cm. Also, no correction was made for transit time of sources according to the IAEA report because the electrometer reading was started after the source has stopped moving.

RESULTS AND DISCUSSION

Readings of measurement at the distance of 20 cm were used to yield the reference air kerma rate in terms of $cGy.s^{-1}$ at 1m from the sources.

The scatter correction was calculated using the previously explained formula and the value of 0.942 was obtained.

For non-uniformity correction the value of 1.006 was yielded according to our calculations. The recommended value for the same IC was 1.004 in Table IX of IAEA report No.1274; however, we used our calculated value for non-uniformity correction.

The air kerma rates provided by the manufacturer were corrected for decay time in terms of the days between the calibration time in the factory and the time of measurement in the hospital. According to the manufacturer, the air kerma rate at the factory had been measured using a well type ionization chamber. The decay time correction was applied for the time interval between the manufacturer's and current measurements. The manufacturer-provided air kerma rate for sources 1, 2 and 3 were respectively 6.195, 6.78 and 5.44 cGy/s at the distance of 1m. The air kerma rates of 6.18, 6.95 and 5.58 cGy/s at 1m were obtained based on measurements in this study. Comparing our results with the manufacturer-provided air kerma rates shows that both air kerma rates are reasonably close to each other for all sources. The differences between measured air kerma rates at the hospital and those measured in the factory were 0.2%, 2.4% and 2.5% for sources 1, 2 and 3 respectively. The uncertainty of 1.5% has been reported for free in-air calibration of ^{192}Ir sources 3 due to the PSDL air kerma calibrations of the chamber used for measurement. However, we did not find any similar document on in-air calibration of ^{60}Co sources. If we consider the geometric uncertainty of our measurement setup, ±2 mm, the dosimetric uncertainty of our measurement could be up to 3%. The observed differences between manufacturer air kerma rate and our results are less than our measurement uncertainty. Our results show that the in-air calibration at the hospital is accurate and it is possible for HDR ^{60}Co sources to check the manufacturer-provided air kerma rates. The uncertainty of in-air measurement could be decreased using a special jig or holder for reproducibility and geometric accuracy of the distance between sources and ionization chambers. However, due to the uncertainties associated with the ionization chamber (Farmer type or well type) calibration in PSDL or SSDL, and also geometric uncertainty in measurement setup, there will be some uncertainty for in-air calibrations of HDR sources.

REFERENCES

1. Chenery SG, Pla M, and Podgorsak EB: Physical characteristics of the Selectron high dose rate intracavitary afterloader, Br. J. Radiol. 1985: 58 (692) 735–740.
2. Flynn A, and Workman G: Calibration of a Microselectron HDR iridium 192 source, Br. J. Radiol.1991: 64 (764) 734–739.
3. International Atomic Energy Agency. Calibration of photon and beta ray sources used in brachytherapy. IAEA-TECDOC-1274. 2002. IAEA, VIENNA, IAEA.
4. Kutcher GJ, Coia L, Gillin M,et al: Comprehensive QA for radiation oncology: Report of AAPM Radiation Therapy Committee Task Group 40, Med. Phys.1988: 21 (4) 581–618.
5. Marechal MH, de Almeida CE, Ferreira IH, and Sibata CH: Experimental derivation of wall correction factors for ionization chambers used in high dose rate ^{192}Ir source calibration, Med. Phys. 2002: 29 (1) 1–5.
6. Nath R, Yue N, Shahnazi K, and Bongiorni PJ: Measurement of dose-rate constant for 103Pd seeds with air kerma strength calibration based upon a primary national standard, Med. Phys.2000: 27 (4) 655–658.
7. Patel NP, Majumdar B, and VijayanV: Study of scattered radiation for in-air calibration by a multiple-distance method using ionization chambers and an HDR ^{192}Ir brachytherapy source, Br. J. Radiol. 2006 79 (940) 347–352.
8. Perera H, Williamson JF, Li Z, MishraV, and Meigooni AS: Dosimetric characteristics, air-kerma strength calibration and verification of Monte Carlo simulation for a new Ytterbium-169 brachytherapy source, Int. J. Radiat. Oncol. Biol. Phys. 1994: 28 (4) 953–970.
9. SelvamTP, Rajan KN, Sethulakshmi P, and Bhatt BC: Monte Carlo aided room scatter corrections in the air-kerma strength standardization of 169Yb and 60Co brachytherapy sources, Phys. Med. Biol.2003: 48(11) N139-N147.
10. Goetsch SJ, Attix FH, Pearson DW, and Thomadsen BR: Calibration of ^{192}Ir high-dose-rate afterloading systems, Med. Phys. 1991: 18 462–467.
11. Kondo S and Randolph ML: Effect of finite size of ionization chambers on measurement of small photon sources, Rad. Res. 1960: 13: 37–60.
12. Bielajew AF: Correction factors for thick-walled ionization chambers in pointsource photon beams, Phys. Med. Biol.1990; 35: 501–516.